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Potential Impacts of Desalination Concentrate on Salinity of Irrigation Water: A Case Study in the El Paso Valley

Texas AgriLife Research and Extension Center at El Paso

May 2008

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Potential Impacts of Desalination Concentrate on Salinity of Irrigation Water: A Case Study in the El Paso Valley

Submitted to
American Water Works Association
U.S. Bureau of Reclamation
and El Paso Water Utilities
in Partial Fulfillment of Project
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Texas A&M University Agricultural Research Center at El Paso

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Contents

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Unit Conversion

1 m^3/s = 2.64 Mm^3/mo = 86,400 m^3/day	1 me/L	Na = 23 mg/L
1 Mm^3 = 811 acre-ft		Ca = 20 mg/L
1 Mm^3/mo = 8.66 MGD		Mg = 12.1 mg/L
1 MGD = 694 GPM = 1.55 cfs = 3.07 AF/day	1 dS m^{-1} = 635 ~ 700 mg/L	

Potential Impacts of Desalination Concentrates on Salinity of Irrigation Water: A Case Study of the El Paso Valley

S. Miyamoto [1,]

Summary

Winter returnflow has not been fully utilized for crop irrigation in the El Paso Valley. There are, however, emerging interests in utilizing it for urban water supply through desalting. This study examined the potential impact of concentrate discharge on salinity, sodicity, and ionic composition of irrigation water supply, using historical or published records. The analyses performed consisted of the estimate of riverflow rates on river water quality, a review of concentrate and permeate quality from nanofiltration (NF) and reverse osmosis (RO), and the impacts of dilution or blending on water quality.

Riverflow and quality data from the U.S. Section, International Boundary and Water Commission (US-IBWC) were examined first. This analysis has shown that salinity and ionic composition of riverflow can be described by a simple power function as related to the momentary riverflow rate when water samples were taken for chemical analyses. This method provides more accurate estimates of monthly salinity than the use of monthly average flow which has a high degree of variation. In addition, this approximation technique allows for the estimation of river salinity and ionic compositions at any riverflow rates of interest.

A review of published articles on NF processes indicates that there are essentially two types of membranes: one has a low rejection rate for Na and Cl, and the other has a high rejection rate. If the objective is to minimize Na and Cl ions while maximizing Ca and Mg concentrations in the concentrate, the first type is preferred. However, the sodium adsorption ratio (SAR) of concentrate from the first type of NF membrane is also influenced by feed water quality. Typically, the SAR of the concentrate does not change appreciably in water that is rich in SO_4, as the rejection rate of SO_4 is high, and SO_4 ions remain in the concentrate along with accompanying cations. The SAR of the concentrate is not necessarily lower than that of feed water, due to the salt concentration effect on SAR. The SAR value which directly impacts the cation exchange reaction in soils decreases with dilution, but increases due to the increased formation of sulfate-divalent cation ion-pairs. Sodicity of the concentrate from the second type is higher than the sodicity of feed water or that of the concentrate from the first type, and approaches the concentrate composition from a RO process. The most significant changes that take place in the concentrate composition from the first type are an increase in TDS and divalent cations and anions, whereas sodicity and chloride concentrations remain more or less the same as those of feed water.

Permeate from the first type of NF membrane is likely to be higher in Na, Cl, and TDS than from the second type. These elevated salt levels limit the opportunity for blending with the river water, which has elevated salinity and SO_4 concentrations, especially at a low riverflow of 5 Mm^3/mo or less. Sodicity and the concentrations of Na and Cl in the permeate could also exceed the unofficial water quality guidelines for irrigating urban landscape. If the RO process or the second type of NF membrane is used, the permeate can be blended with river water at nearly a 1:1 ratio. This means that a lesser quantity of water needs to be treated when a RO

process is used. If river water high in Na and Cl concentrations is used for blending, the salt load of the concentrate from the NF process can actually be greater than that from the RO process, because of the limited blending possibility. If the NF option is to be retained, a NF membrane with some rejection of Cl ions may be warranted, unless blending water low in Cl is available at or near the site.

Assuming that flow and salinity monitoring data at the Courchesne Bridge are realistic, the disposal of NF concentrate from 5 and 10 MGD membrane processes at a riverflow rate of 5 Mm^3/mo may increase salinity of riverwater by around 7 and 16%, respectively, over the existing salinity. This estimate is for a NF membrane with a low rejection for Cl ions, and applies to the situation of low flow periods, around 5 Mm^3/mo. At a riverflow rate of 10 Mm^3/mo (which is close to the median flow), salinity increases associated with 5 and 10 MGD plants are estimated at 3.5 and 7.0%, respectively. Salinity increases from RO processes or the NF membrane with high Na and Cl rejection rates would be somewhat higher. The use of a two-stage process (the NF first, then the RO process) for the permeate increases the potential for blending, provided that a cost-effective means of disposing the RO reject (dominated by NaCl) can be found at the site in question. The quantity of salts, which may be removed in the second stage, is about ¼ of the total salt loading or about 15 tons of NaCl/day (460 tons/mo) at a 5 MGD processing capacity. Salinity of the blend is reduced when it is mixed with reclaimed municipal effluent, which has lower salinity. However, the effect of concentrate disposal to the mixture of river water and reclaimed water will persist. Impacts of these water quality changes on soil salinity and winter crop production are yet to be analyzed. A possibility exists in some crops that crop response may not be proportional to the projected increases in TDS, as ion activities and species are going to be altered by the discharge of NF concentrate. This aspect is scheduled to be studied in the follow-up phase of this project.

Introduction

Urbanization of irrigated areas is usually accompanied by the conversion of water use from irrigation to urban uses. In the case of the El Paso Valley located in the middle Rio Grande Project Area, nearly 80% of the urban water supply is met during irrigation seasons (March-September) by using river water. During nonirrigation seasons (October-February), however, river water is not used for urban water supply, due to high salinity and elevated SO_4 concentrations. The Texas standards for TDS and SO4 are 1000 and 300 mg L^{-1}, respectively, where as the federal standards for TDS and SO_4 are 500 and 250 mg L^{-1}, respectively. The El Paso Public Service Board is interested in conserving the ground water currently used for public water supply by making use of winter returnflow through desalination and other necessary treatments.

The most prevalent method of desalination is reverse osmosis (RO). It can produce high quality water for blending, but also yields concentrate high in dissolved salts. The use of nanofiltration (NF) also produces saline concentrate, but is comparatively rich in divalent ions. Divalent cations help stabilize soil structure as well as growth of Na sensitive plants (e.g., Maas 1990; Shainberg, 1990). Disposal of NF concentrate into existing irrigation systems is thus considered a plausible disposal option. However, pilot testing of NF (e.g., Riley, 2005; Turner et al., 2002) shows that a significant quantity of monovalent cations (usually Na) appears in the concentrate when Ca plus Mg concentrations are lower than that of SO_4 concentrations in terms of chemical equivalent. The filtration of NaCl is membrane-dependent (e.g., Lee et al., 2003; Mulford et al., 1999), but is also influenced by the electrostatic equilibrium across the membrane (e.g., Weisner and Buckley, 1996). The quality of concentrates from the NF process must be examined carefully, prior to assuming that the concentrate will be low in sodicity.

The purpose of this study was to review the ionic compositions of NF concentrate, then to estimate the impact of concentrate blending on salinity and ionic concentrations of water used for irrigation during winter months (October-February). The assessment of potential impacts on soil salinity and winter crop production in the El Paso Valley is beyond the current phase, and is scheduled to be addressed in the follow-up phase.

The Study Area

The El Paso Valley consists of the Upper and the Lower Valleys which are separated by a narrow geological gap known as the Pass to the North (Fig. 1). The water treatment plant in consideration for membrane filtration and/or reverse osmosis is located just below the gap, and is locally known as the Canal Plant. The area, which can be impacted by the treatment of winter returnflow, includes the Lower Valley with a total irrigated area of 33,600 ha (US-IBWC, 2003), and possibly some areas in the adjacent district below (the Hudspeth Irrigation District), since wastewater streams are designed to flow into the district through access drains.

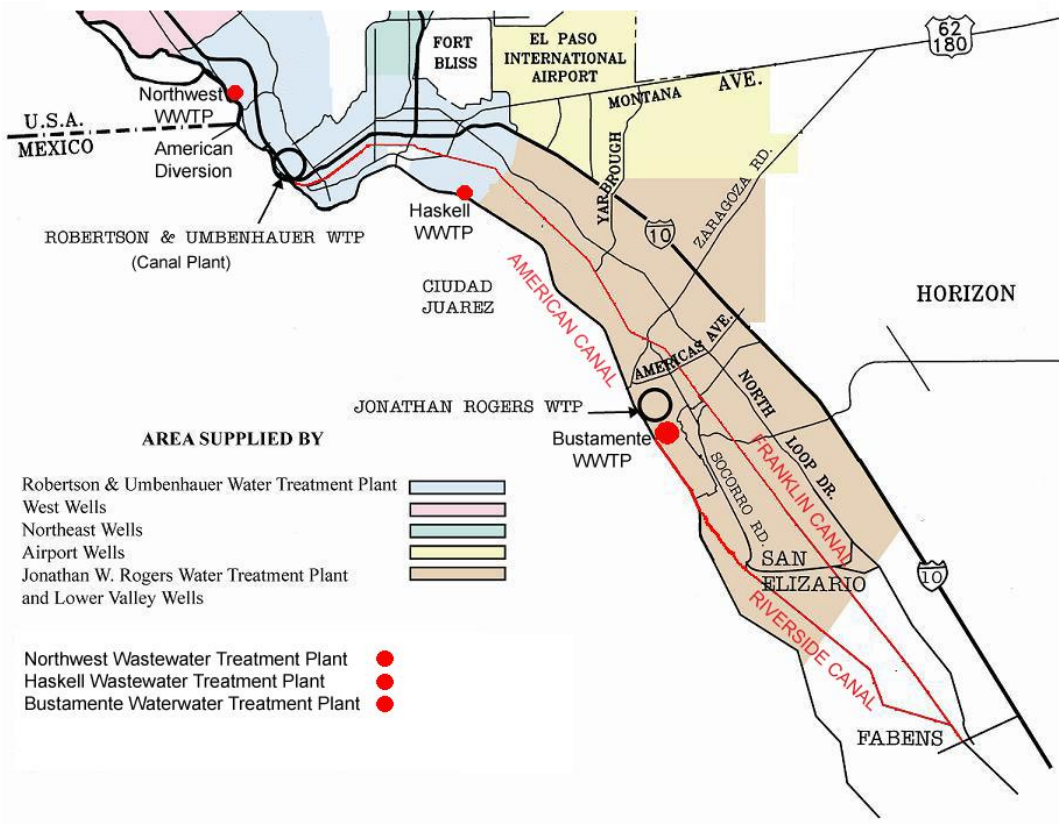

Fig. 1. A sketch of the El Paso Valley and water treatment/conveying facilities.

Cropping Patterns and Water Requirements

The main crops grown in this valley are cotton, pecans, alfalfa, and several vegetable crops. During winter months, onions, wheat, and alfalfa are the main crops grown (Table 1). Lettuce, which is the main winter crop in the Mesilla Valley located upstream, is also grown in the Lower Valley, but in a small acreage due to water quality constraints. The current winter cropping totals 2,400 ha with an estimated consumptive water requirement of about 5 Mm^3 (4,000 AF) for the winter period. The crop acreage figures listed are from the U.S. Bureau of Reclamation (BOR) for 2005. The types of crops to be grown along with their planned acreages may change in the future. These changes, if known to occur with certainty, may be taken into consideration for estimating the winter water requirement.

The estimates of crop consumptive use are from the BOR database (BOR, 1972). The water delivery requirement was assumed to be two times the estimated consumptive requirement. Alfalfa is usually irrigated until October or November. Some pecan orchards are irrigated in January or February with returnflow, especially during years of low water supply. Winter irrigation of pecans uses as much as 15 to 20 cm of water per application for salt leaching. The water delivery requirements for winter irrigation of pecans, divided equally for January and February, are estimated at 1.5 Mm^3 (1,200 AF), if all growers use it.

Table 1. An estimate of water requirements for irrigated production of winter crops in the El Paso Lower Valley (crop acreage figures by USDI, Bureau of Reclamation).

		Oct	Nov	Dec	Jan	Feb	Total	
Potential Evaporation		----------cm/mo----------					cm	in
(Penman Estimate)		13.4	9.0	6.9	6.9	11.4	47.6	18.7
Evapotranspiration								
Onion		(15)[1] -	3.0	3.0	3.2	5.3	29.5	11.6
Wheat		-	-	(15)	3.0	7.8	25.8	10.2
Alfalfa		14.2	8.8	-	-	-	23.0	9.1
Pecans		-	-	-	(15)[1] -	-	(15)[1] -	(6.0)[1] -
Water Requirement[2] -								
	(ha)	----------Mm^3/mo----------					Mm^3	1000 AF
Onion	(400)	1.20	0.24	0.24	0.25	0.42	2.35	1.91
Wheat	(400)	-	-	1.20	0.24	0.62	2.06	1.67
Alfalfa	(1000)	2.84	1.76	-	-	-	4.60	3.37
Pecans	(500)	-	-	-	0.75	0.75	1.50	1.22
Total	2420	4.04	2.00	1.44	1.24	1.79	10.51	8.53

[1] - Winter irrigation mainly for crop establishment or salt leaching.

[2] - Delivery and application losses were assumed to be 50%.

*1 Mm^3 = 1 million m^3 = 811 acre-ft.

Water Conveying Infrastructure

The flow of the Rio Grande is regulated at Elephant Butte Reservoir located 190 km (120 miles) upstream. The river water is taken into American Canal through American Diversion Dam, then into Franklin Canal from Franklin Diversion. The Canal Water Treatment Plant is located in the vicinity of the head work of the Franklin Canal. This plant supplies potable water to the Central District Water Service Area by treating river water during irrigation seasons. During nonirrigation seasons, water supply to the Central District is from ground water piped from outside of the service area. Domestic use of the water returns back to Haskell Wastewater Treatment Plant (WWTP) located approximately 5.6 km (3.5 miles) downstream from Canal Water Treatment Plant. Discharge from Haskell WWTP is ordinarily directed to American Canal, which runs along the river. The concentrate from the membrane process, if discharged to American Canal, is likely to be diluted by river water and the discharge from the Haskell Plant. Discharge to Franklin Canal is also a possibility, but the flow can not be blended with municipal returnflow, until it reaches Fabens.

The Bustamante Wastewater Treatment Plant, located 20 km (12 miles) downstream of Haskell Wastewater Treatment Plant, receives municipal effluent from the East and the Lower Valley Service areas. Discharge from this plant is either to Riverside Canal or to Hudspeth access drain, which conveys water to the Hudspeth Irrigation District located below the El Paso Irrigation District. During years of short water supply, as well as in winter months, reclaimed water from Bustamante WWTP is taken into Riverside Canal, along with discharge from Haskell WWTP for irrigation. The Riverside Canal and the Franklin Canal merge at Fabens to form Tornillo Canal. Drainage water is routed through open drains, and its quality deteriorates

severely in Tornillo Drain where salinity ranges from 2,000 to 3,000 mg L^{-1} (EPCWID, unpublished data).

Water Availability and Quality

Two sources of water are available for irrigation during winter months; river water and reclaimed water from two wastewater treatment plants, Haskell and Bustamante WWTP. The largest quantity of water available during winter comes from the Rio Grande in the form of irrigation returnflow (Table 2). The median monthly flow since 1936, determined by Riley (2005), is 11.7 Mm^3/mo (101 MGD) for October through February, and 8.1 Mm^3/mo during December and January. Unfortunately, the flow of the river is highly unstable, and the standard deviation equals the mean. At median flow, the water available from the river is 5 to 7 times the current estimated demand. Reclaimed water from Haskell and Bustamante Plants combined adds an additional 4.8 Mm^3/mo (41 GPD) of relatively stable flow. In theory, discharge from the Haskell WWTP alone is sufficient to meet the irrigation water demand, except for the months of October and November. However, there seem to be several logistic problems of delivering small flow (23 cfs) through the district irrigation systems designed for high flow irrigation as well as the long-standing agreements on water delivery to the Hudspeth District.

Table 2. The quantity and salinity of water available for irrigation during off-seasons.

		Oct	Nov	Dec	Jan	Feb	Average
Discharge							
River water (1936 - 2004, USGS)							
median[1] -	Mm^3/mo	21.3	11.1	8.8	7.4	9.7	11.7
	MGD	183	96	76	64	84	101
Haskell WTP	(2001 - 2005, EPWU)						
mean	Mm^3/mo	1.88	1.61	1.55	1.48	1.78	1.66
	MGD	16	16	16	13	16	15.4
SD	MGD	0.08	0.14	0.08	0.15	0.16	0.12
Bustamante WTP	(2001 - 2005, EPWU)						
mean	Mm^3/mo	3.17	3.09	3.14	3.06	3.11	3.11
	MGD	27	27	27	26	27	26.8
SD	MGD	0.21	0.18	0.29	0.19	0.24	0.22
Salinity (mg/L)							
River water (1970 - 2002, excluding 1985, IBWC)							
mean		1226	1400	1459	1411	1263	1352
SD		237	242	203	323	392	279
Haskell WTP	(2001 - 2005, EPWU)						
mean		886	829	804	773	836	826
SD		59	38	78	107	87	74
Bustamante WTP	(2001 - 2005, EPWU)						
mean		1160	1085	1102	1086	1036	1094
SD		52	25	98	74	68	63
Sodicity (SAR)							
River water, mean		5.94	6.65	7.11	7.00	6.93	6.73
Haskell WTP, mean		6.77	7.22	7.17	7.05	7.21	7.08
Bustamante WTP, mean		7.48	8.39	8.41	8.61	8.36	8.25

Mm^3/mo = 264 Million gallons/mo ≈ 8.66 MGD, 1 MGD = 1.55 cfs = 3785 m^3/day

[1] - The computation of the median flow was performed by Riley (2005) for a period of 1936-2004.

Salinity of river water is, as described later, dependant on its flow. The monthly salinity well exceeds 1,000 mg L^{-1}, and the sodicity expressed by the sodium adsorption ratio (SAR) is around 7.0 or less (Table 2). Salinity of the Haskell WWTP discharge averages 826 mg L^{-1} with a SAR of 7.0. Salinity of Bustamante WWTP averages 1,094 mg L^{-1} with a SAR of 8.0. This wastewater stream has higher Na and Cl concentrations than the discharge from the Haskell Plant. Salinity, but not sodicity, of the discharge from both Bustamante and Haskell is, however, lower than that of the river water during nonirrigation seasons. Additional details on monthly water quality are shown in Table A-1 of the Attachments.

Quantity and Quality of Source Water

The availability of river water during winter months was analyzed by Riley (2005), using the USGS flow data since 1936 (Table 3). According to his analysis, 80% of the recorded monthly flow exceeded 4.6 Mm^3/mo (40 MGD) for the past 68 years. The percentile increased to around 90% when 2.3 Mm^3/mo (20 MGD) was chosen. The flow of 4.6 Mm^3/mo (40 MGD) corresponds to about half of median riverflow from December to February.

The source water considered for treatment is the river water which consists of irrigation returnflow and a small discharge from Northwest WWTP. The quantity and quality of the flow have been gauged by the U.S. Section of the International Boundary and Water Commission (US-IBWC) at the Courchesne Bridge, 2.7 km above American Diversion Dam. Fig. 2 shows the changes in flow expressed as a sum of monthly flow for October through February. There was a large release of water in 1986 and 1987. Otherwise, the flow during winter months increased since 1968 until 1994, then decreased again. The mean salinity of winter flow after the high flow event decreased with a great deal of fluctuation until 1994, then has increased since. The annual mean salinity averaged around 1,600 mg L^{-1} prior to the flood of 1986, then decreased to around 1,200 mg L^{-1} after the flood.

Table 3. The percentage of the months when riverflow exceeded the specified flow rates for the past 68 years, and the average concentration of total dissolved salts (TDS), sulfate (SO_4), and chloride (Cl) at the specified flow rates (Riley, 2005).

Flow rate	(Mm^3/mo)	4.62	2.31	1.15
	(MGD)	40	20	10
Percentile of the months exceeding the specified flow				
	Oct	87	94	97
	Nov	82	88	91
	Dec	79	87	90
	Jan	78	88	91
	Feb	72	85	90
	Avg	80	89	92
Estimated quality at the specifiec flow rates[1] -				
Salinity (mg/L)	Oct - Feb	1407	1780	2292
SO_4 (mg/L)	Oct - Feb	453	586	726
Cl (mg/L)	Oct - Feb	287	335	512

[1] - These values were obtained through regression between water quality and flow rates by Riley

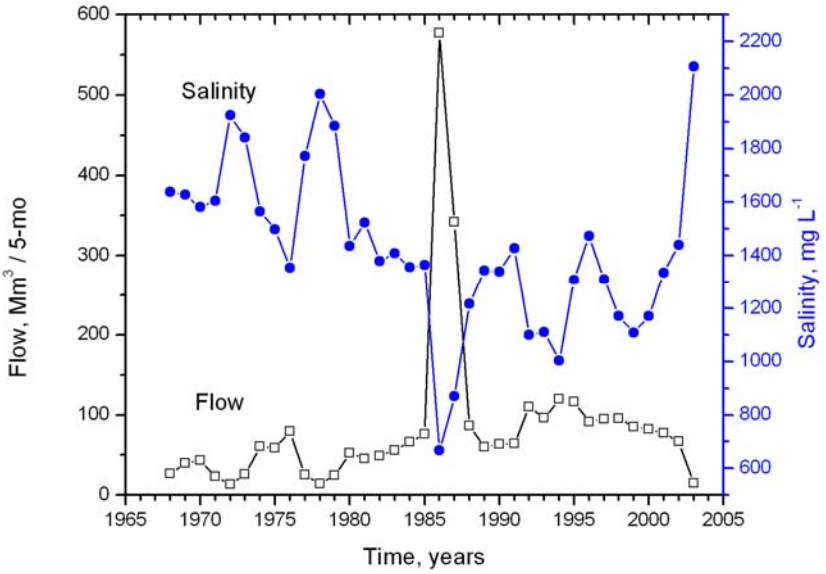

Fig. 2. Flow and salinity of the middle Rio Grande at El Paso since 1968. The salinity is an arithmetic mean of monthly salinity estimated from the conductivity readings with a conversion factor of 690 mg L^{-1}/dS m^{-1} (Data source: US-IBWC).

According to the US-IBWC data, flow of the Rio Grande prior to the 1970s was even lower, especially during the 1950s. Such a low flow condition may be partially offset in the future by discharge from Northwest WWTP, as the service area is expanding rapidly. The current discharge from NW Plant during winter months is 1.0 Mm^3/mo (8.7 MGD) at an average salinity of slightly below 1200 mg/L.

Salinity of riverflow varies with flow. Fig. 3 shows monthly salinity for two periods, 1970-1984 (prior to the high flow) and 1900-2000 (after the high flow). The monthly flow rate shown is the sum of the recorded daily flow.

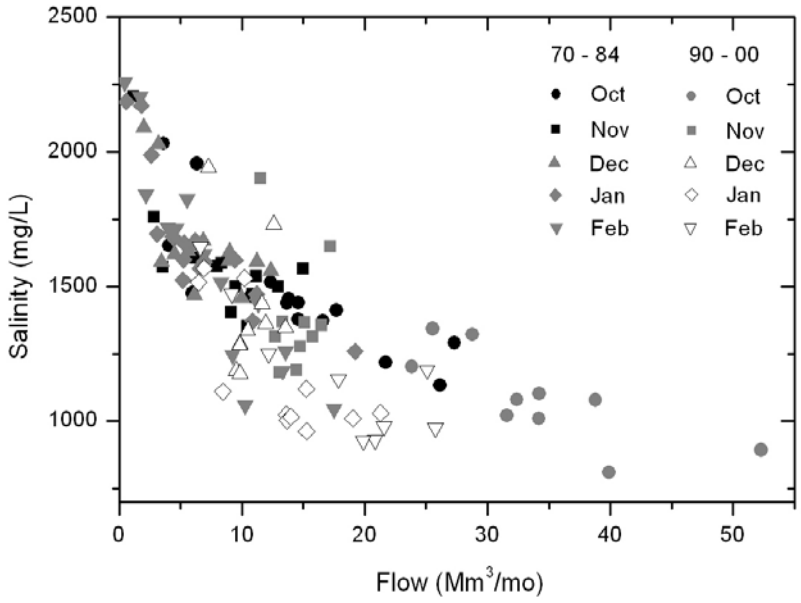

Fig. 3. The relationship between monthly flow and streamflow salinity estimated from conductivity readings during 1970-1984 prior to high flow, and during 1900-2000 after the high flow.

Although there is a clear tendency for salinity to increase with decreasing flow, there are considerable ranges in salinity at a given flow rate, e.g., from 1,000 to 1,600 mg L^{-1} at a monthly flow rate of 10 Mm^3/mo. It is also apparent that salinity of the flow during October and November (shown by dark shaded symbols) tends to be higher than that of the later months. The riverflow during September through November consists largely of agricultural drainage water. Using this type of regression analysis for a period of 1936-2005, Riley (2005) provided an estimate of the mean concentration of TDS, SO_4 and Cl at the specified flow rates. These are shown in Table 3 which was introduced earlier. Such an estimate, however, has a wide range of deviation. An alternative method of data handling has to be used, if salinity is to be projected at a given flow rate with greater accuracy.

Methods for Estimating Concentrate Effects

Incoming Riverflow and Salt Concentration

Salinity of the incoming riverflow has historically been measured using water samples collected once or twice a month, whereas the streamflow has been measured daily. We found a poor correlation between the mean daily flow estimated from the monthly mean flow and the momentary flow at the time of water sampling, except during low flow periods (Fig. 4).

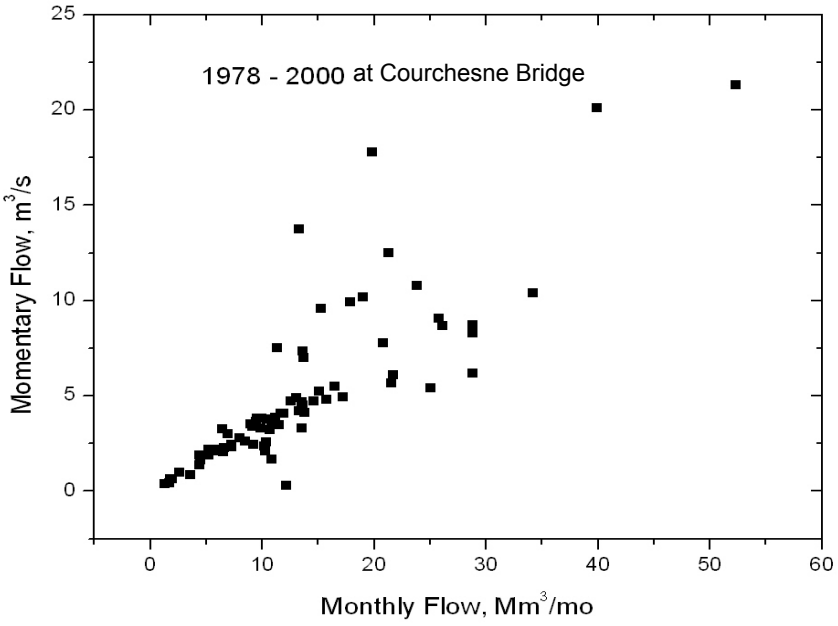

Fig. 4. The relationship between monthly flow and momentary flow at the time of salinity measurements (Data Source: US-IBWC).

We used the following equation to describe the relationship between the salt flux and the momentary flow at the time of water sampling for salinity.

$$cq = \alpha q^{\beta} \quad (1)$$

where c is the salinity or the ion concentration of the streamflow, q is the momentary flow at the time of water sampling, and α and β are empirical coefficients. The product of c and q is referred to as the (salt) flux, and carries a unit of mass per time.

Once α and β are determined using the flow rate during sampling, the monthly salinity or the ion concentration averaged over a month may be adjusted as

$$C_m = \left(\Sigma c_i q_i / \Sigma q_i\right)\left(Q_m / \Sigma q_i / N\right)^{\beta-1} \tag{2}$$

where C_m and Q_m are the monthly flow-weighted salinity and the monthly flow, respectively, and N is the number of sampling per month. Subscript i denotes each sampling within a month. For estimating salinity as related to monthly flow, Q_m can be substituted for q in Eq. 1.

Riverflow in the semi-arid areas fluctuates widely. In some instances, it may be possible to have discharge from wells to supplement the drought-induced shortage, such as practiced in the Lower Valley. In such cases, salinity of the blend should be computed by Eq. 18 given later.

Salt Balance in Membrane Processes

Once the source water is diverted, it is assumed to undergo pre-filtration and membrane processes (Fig. 5).

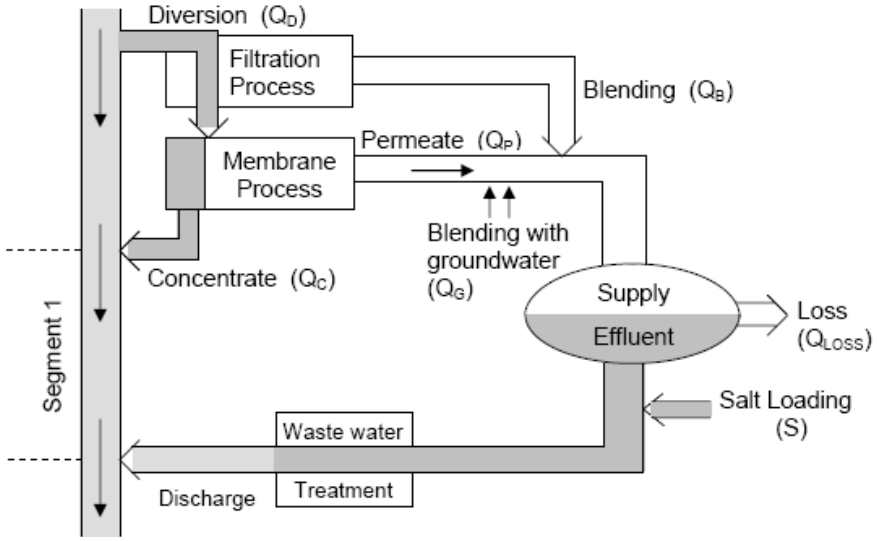

Fig. 5. A schematic of water diversion, processing, distribution, return, and discharge back into the source water.

The following salt balance was assumed to apply

$$c_D Q_D = c_C Q_C + c_P Q_P \tag{3}$$

where c denotes the ion concentration, Q the flow rate, and subscripts $_D$, $_C$, and $_P$ denote the diversion, the concentrate, and the permeate, respectively. Under a steady-state assumption, Q_D equals Q_C plus Q_P.

Two common parameters: the rejection rate σ, and the recovery rate, R, are defined as

$$\sigma = (c_D - c_P) / c_D \tag{4}$$

$$R = Q_P / Q_D \tag{5}$$

Rewriting Eq. 3 for $c_C Q_C$ using Eqs. 4 and 5, we obtain

$$c_c Q_c = \left[1 - (1 - \sigma)R\right] c_D Q_D \tag{6}$$

$$c_c = \left[\frac{1 - (1 - \sigma)R}{1 - R}\right] c_D \tag{7}$$

when $c_P = c_D$ (the case of free passage), σ = 0. Eq. 6 reduces to $c_C Q_C = [1 - R] c_D Q_D$, and Eq. 7 to $c_C = c_D$. When $c_P = 0$ (similar to a reverse osmosis case), σ = 1. Eq. 6 is reduced to $c_C Q_C = c_D Q_D$, and Eq. 7 to

$$c_C = \left[1 / (1 - R)\right] c_D, \quad c_P = 0 \tag{8}$$

The rejection rate σ is affected by membrane types, water quality, and operating conditions, and is to be determined by a pilot test or a review of similar systems. The recovery rate is an operational parameter, and is determined by considering fouling of the membrane, along with other factors.

Blending Processes

Concentrate from nanofiltration or reverse osmosis is subject to a series of blending, which is outlined below.

Permeate Blending: Permeate from reverse osmosis usually contains very low concentrations of dissolved salts. It is then used to dilute the pre-filtered diversion flow. In nanofiltration, permeate may also be used to dilute the pre-filtered row water to a concentration not to exceed the regulatory limits for TDS, SO_4, or Cl.

$$c_U Q_U = c_P Q_P + c_B Q_B \tag{9}$$

where subscript $_B$ denotes the water to be used for blending, and $_U$ is the urban water supply after blending.

Rewriting Eq. 9

$$c_U = \frac{(c_P Q_P + c_B Q_B)}{Q_P + Q_B} = \frac{c_P + c_B R_B}{1 + R_B} \tag{10}$$

where

$$c_P = (1 - \sigma) c_D \tag{11}$$

$$R_B = Q_B / Q_P \tag{12}$$

and R_B will be referred to as the blending ratio.

Eq. 9 or Eq. 10 can be rewritten in a form convenient for estimating the blending ratio to achieve the desired quality of the blend.

$$\mathrm{R_B} = \frac{1 - c_p / c_u}{c_B / c_u - 1} = \frac{Q_u}{Q_p} - 1 \tag{13A}$$

$$\mathrm{Q_p} = Q_u / (R_B + 1) \tag{13B}$$

When c_p is zero, similar to the permeate from a RO process, Eq. 13 is simplified to $R_B = \mathrm{c}_u/(\mathrm{c}_B - \mathrm{c}_u)$. This equation does not apply when c_B is less than c_u.

Concentrate Dilution with Source Inflow: The concentrate, if discharged to the surface stream, was assumed to be diluted by the incoming flow

$$cQ = c_D(Q_{IN} - Q_D) + c_C Q_C \tag{14}$$

or

$$cQ = c_D(Q_{IN} - Q_D) + c_C(1 - R)Q_D$$

The flow after blending (Q) is equal to $Q_{IN} - Q_D + Q_C$.

We now define the dilution ratio D_R as

$$D_R = (Q_{IN} - Q_D) / Q_C \tag{15}$$

Rewriting Eq. 9, using D_R

$$c = \frac{c_D(Q_{IN} - Q_D) + c_C Q_C}{Q_{IN} - Q_D + Q_C} = \frac{c_D D_R + c_c}{(D_R + 1)} \tag{16}$$

When D_R is much greater than 1, Eq. 16 is reduced to $c = c_D + c_c / D_R$.

The sodium adsorption ratio (SAR), by definition, decreases with dilution

$$SAR = SAR_c / \sqrt{c_c / c} \approx SAR_c / \sqrt{(D_R + 1) / \left[(c_D / c_c)(D_R + 1)\right]} \tag{17}$$

where *SAR* is the sodium adsorption ratio after dilution, SAR_c is the SAR of the concentrate, *c* is the ion concentration of the blend computed by Eq. 7 or 8, or using the approximation given above. When D_R far exceeds 1, the above equation is reduced to $c_c/c = c_c/c_D$. In all cases, salt precipitation is ignored for simplicity.

***Sequential Blending*:** The incoming surface water blended with the concentrate from the membrane processes can undergo additional blending with discharge from other sources, such as those from wastewater treatment plant(s).

$$cQ = c_1(Q_1 - Q_{LOSS}) + c_2Q_2 + c_3Q_3 \tag{18}$$

where $$Q = (Q_1 - Q_{LOSS}) + Q_2 + Q_3$$

where Q_{LOSS} is the nonevaporative loss of water prior to blending with water sources designated by numeral 2 and/or 3.

If Eq. 18 is to be used for estimating salinity of the streamflow which has received the discharge from various wells, c_1 and Q_1 represent the salinity and the flow rate of the riverflow prior to blending with the well water, and Q_2 and Q_3 denote the discharge from the wells.

Results

Incoming Riverflow and Salt Concentration

The relationship between the momentary flow and the salt load closely followed Eq. 1. An example is shown in Fig. 6 using a full-log scale. Additional plots for individual ion species are shown in Fig. A-1 of the Attachments. The coefficient of correlation was upward of 0.95.

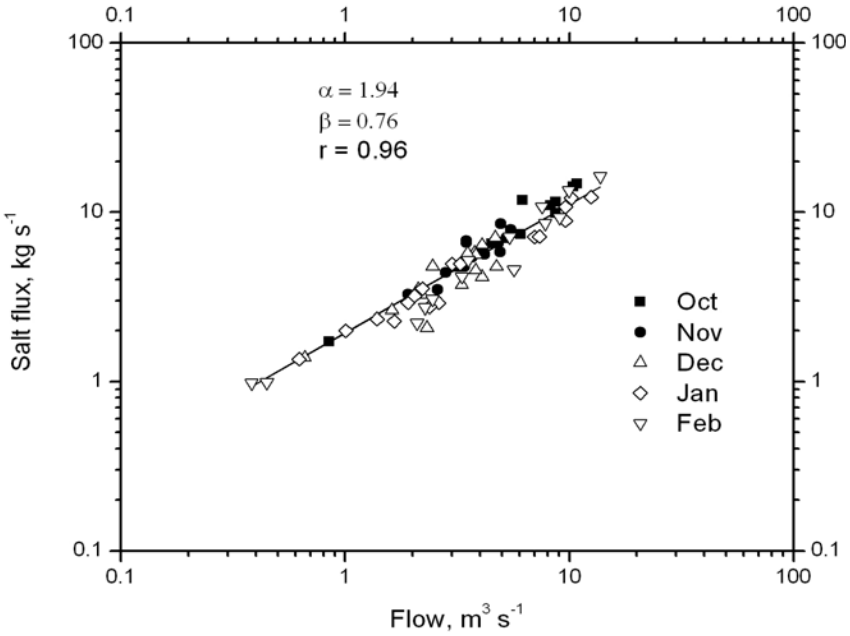

Fig. 6. An example of the relationship between salinity and momentary flow at the time of water sampling.

The empirical coefficients determined as the best fit are listed in Table 4. Note that coefficient α is equal to the salt concentration when q is unity. Coefficients α and β were determined when the concentration, the same as *c*, and the flow rate, *q*, were expressed in mg/L and m^3/s, respectively. Coefficient β is independent of the unit for *q*. However, α is dependent of the unit for *q*, and *c*. When *q* was expressed in Mm^3/mo, α was adjusted to $\alpha / (2.64)^{\beta-1}$. Note that 2.64 is an approximate conversion factor from m^3/s to Mm^3/mo. In Fig. 6, the salt flux is shown as kg/s, instead of g/s, which are 1/1,000 of the units used in Table 4. The empirical coefficients shown in Table 4 for TDS are based on a sum of cations and anions, and are slightly different from those shown in Fig. 6 where TDS was estimated from the electrical conductivity.

Table 4. The empirical coefficients for estimating salt concentrations from flow rates.

	α	α	β	r		α	α	β	r
	Q (m^3/s)	Q (Mm^3/mo)				Q (m^3/s)	Q (Mm^3/mo)		
Salinity									
Oct - Nov	2260	3030	0.70	0.92					
Dec - Feb	2110	2920	0.67	0.93					
Combined	2100	2830	0.69	0.97					
Na					**HCO_3**				
Oct - Nov	482	685	0.64	0.94	Oct - Nov	426	520	0.80	1.00
Dec - Feb	459	680	0.59	0.96	Dec - Feb	392	486	0.78	0.99
Combined	462	665	0.62	0.95	Combined	391	471	0.81	0.99
Ca					**Cl**				
Oct - Nov	163	199	0.80	0.97	Oct - Nov	391	549	0.65	0.86
Dec - Feb	148	182	0.79	0.98	Dec - Feb	381	545	0.63	0.96
Combined	151	182	0.80	0.98	Combined	381	538	0.64	0.94
Mg					**SO_4**				
Oct - Nov	39	48	0.79	0.97	Oct - Nov	718	982	0.68	0.97
Dec - Feb	37	47	0.76	0.98	Dec - Feb	667	964	0.62	0.96
Combined	32	39	0.80	0.97	Combined	675	938	0.66	0.96

For estimating the salt concentration for a given flow rate, it may be simpler to use the following expression which is an alternative expression of Eq. 1.

$$c = \alpha Q^{\beta-1} \tag{19}$$

where *c* is the ion concentration, *Q* is the riverflow rate, and α and β values are given in Table 4.

The salt concentrations computed from Eq. 19 at a flow rate of 5, 7, 10, 15 and 20 Mm^3/mo (43, 61, 86, 130 and 173 MGD) are shown in Table 5. The results were checked by comparing the sum of cations and anions against the TDS estimated, as well as the sum of cations and anions in chemical equivalent. As shown in the last two columns of Table 5, a good agreement was found between the cation and anion totals. (The graphical presentation of the computed results is given later in Fig. 7).

The standard error of the estimate was not determined. However, judging from the plots shown in Fig. A-1, there is little deviation from the best fit-line when the flow is below 2 to 3 m^3/s or 5 to 8 Mm^3/mo. Recall that the median flow during December through January is 8.1

Table 5. The estimated salinity and ion concentrations of the river water at given flow rates.

Riverflow			TDS	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4	ΣC^1-	ΣA^1-
			mg/L	$(mmol/L)^{1/2}$	mg/L						----(me/L)----	
Mm^3/mo	MGD											
5	43	Oct-Nov	1851	7.41	380	143	34	373	311	581	26	27
		Dec-Feb	1699	7.65	375	129	32	342	299	520	25	25
7	61	Oct-Nov	1646	6.77	336	133	32	348	276	521	25	25
		Dec-Feb	1512	6.94	327	120	29	317	263	456	23	22
10	86	Oct-Nov	1499	6.21	296	124	29	323	244	465	22	22
		Dec-Feb	1350	6.24	283	111	27	292	232	399	20	20
15	130	Oct-Nov	1325	5.57	255	114	27	297	212	408	19	19
		Dec-Feb	1180	5.54	240	102	24	266	199	342	18	17
20	173	Oct-Nov	1214	5.15	230	108	26	280	191	371	18	18
		Dec-Feb	1072	5.06	213	96	23	249	179	307	16	16

[1]- The sum of cations and anions for Oct. and Nov. in chemical equivalent.

Mm^3/mo (Table 2). When the flow exceeds the median, the deviation from the estimate becomes large. However, our concern is mainly in the range below the median flow. In any case, the error of the estimate is much smaller than the method involving the monthly average, which registered the coefficient of variability in excess of 20%. The salt concentration of river water depends mainly upon the flow rate, more so than months of the year.

Recall that the TDS and the concentrations of SO_4 and Cl at a flow rate of 4.6 Mm^3/mo (40 GPD) was previously estimated by Riley (2005) as 1,407, 453 and 287 mg/L, respectively (Table 3). The new estimates for TDS, SO_4, and Cl at the flow rate of 5 Mm^3/mo (43 GPD) are 1,851, 581, and 311 mg/L for the period of October through November (Table 5). For the period of December through February, the corresponding values were 1,699, 520 and 299 mg/L, both of which are significantly higher than the earlier estimates by Riley (2005). (As shown later, the estimate of salinity and ion concentrations of source water affects those of concentrate and permeate). When the riverflow increases to 10 Mm^3/mo (86 MGD), salinity during December through February was estimated at 1,350 mg L^{-1}. This can be compared with the measured mean of 1,380 mg/L for the same period.

According to the simulated results (Table 5), the TDS limit of 1,000 mg/L and the sulfate limit of 300 mg/L cannot be met unless the flow exceeds at least 20 Mm^3/mo (173 MGD). In order to meet the Cl limit of 300 mg L^{-1}, the flow rate needs to be somewhere between 5Mm^3/mo (43 MGD) and 10 Mm^3/mo (86 MGD), or higher.

Salt Balance in Membrane Processes

Reported Cases: The information on nanofiltration (NF) and reverse osmosis (RO) is available in various publications. Earlier work has focused on membrane performance. Lee et al. (2003), for example, compared five aromatic polyamide composite low pressure RO and NF membranes in rejection of $CaCl_2$ and NaCl from saline solutions. These membranes were LFC-1 and ESPA-1 offered by Hydranautics, TFU-ULP and TFC-HR by Koch Membrane Systems, and NF-90 by Dow Film Tech. Test results have shown varying degrees of removal of $CaCl_2$ and NaCl as shown in Table A-2 of the Attachments. Three of the membranes tested provided over 95% of

rejection, and others 77 to 87%. The report also indicates that the removal of NaCl by certain membranes also depends on the salt concentration of the feed solutions.

Some performance tests were conducted using one type of membrane, but under different film areas and production units. Mulford et al. (1999), for example, reported results of a nanofiltration pilot study and a full-scale performance involving different membrane areas, and the number of elements per pressure vessel, and varying degrees of production rates. Some of these results are shown in Table A-2 when tested for ground water having 475 mg/L of TDS. Note that this feed water had a high Ca concentration as compared to Na, thus yielding a low SAR value in the permeate as well as in the concentrate. The membrane used was NF-70 by Dow Chemical, which provided rejection rates of over 90% for divalent ions, and below 60% for monovalent ions.

Chang et al. (2005) used a RO membrane (Nanomax 95 by Millipore) and a NF filter (Nanomax 50) for desalting municipal effluent with low salinity (396 mg/L). They reported high rates of rejection of divalent ions (88% by the NF membrane), but the rejection rate of Cl was only 20% (Table A-2).

Turner et al. (2002) treated river water with nanofilter 2540 ESNA by Hydranautics. Unlike the feed water tested by Mulford et al. (1999) or by Chang et al. (2005), this feed water contained Na as the dominant cation (Table A-2). The divalent ions were rejected at or near 90%, whereas the rejection of Na and Cl was 76 and 63%, respectively. Dealing with river water with a slightly higher salt concentration (804 mg/L) than that used by Turner et al. (2002), Riley (2005) reported 89 and 78% rejection of Ca and Mg, along with 91% rejection of SO_4 using a nanofilter, E4-2200-DLX by Osmonics. However, the rejection of Na and Cl was lower (24 and 6%, respectively) than the rejection rates reported by Turner et al. (2002). The difference in Na and Cl removal is likely caused by the difference in membrane type and pre-treatment of HCO_3 ions.

Nanofiltration of irrigation returnflow containing 2,015 mg/L of TDS is currently evaluated by using a membrane from Osmonics by Tarquin et al. (Unpublished). Their preliminary data (Table A-2) indicate that the rejection rate for SO_4 was 91%, whereas Cl has passed through. The rejection of Ca and Mg has been lower than the figures reported by Turner et al. (2002) or Riley (2005). However, the charge balance seems to indicate that the rejection rate for Ca is underestimated and could be as high as 82% if the Ca concentration measured in the concentrate is used for computation.

Ferjani et al. (2004) used polymethyl-hydrosiloxane (PMHS) to filter brackish water with TDS of 4,100 mg L^{-1}. This experimental membrane provided a rejection rate as high as 98% for divalent ions, and over 80% for Na and Cl from highly saline water rich in Na and Cl. Le Gouellec and Elimelech (2002) reported high levels of rejection using NF-90 by Dow Chemical for treating highly concentrated saline agricultural drainage water, with the TDS of 17,700 and 23,500 mg L^{-1}. These salt levels are, however, outside the range of salinity of our concern.

Rejection Rate and Concentrate Composition: From the review given above, it is evident that the performance of nanofilters depends on membrane types as well as quality of feed water.

Table 6 summarizes reported rejection rates. The reported cases are consistent in regard to the high rejection rate of SO_4 (89-99%). The rejection of HCO_3 could not be confirmed, because it is often removed by acid application to avoid membrane fouling. With the exception of the initial testing by Tarquin, the rejection rate of Ca and Mg by nanofilters are also fairly consistent, 80-99%.

Table 6. Reported rejection efficiency of nanofiltration and reverse osmosis process.

	Feed Water		Rejection Efficiency						Concentrate[1]	
	TDS	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4	TDS	SAR
	mg/L	$(mmol/L)^{1/2}$	- - - - - - - - - - % - - - - - - - - - -						g/L	(mmol/L
Mulford, et al. (1999)										
Nanofiltration NF-70	475	0.71	61	85	90	68	55	98	2.1	1.2
Pilot Test	475	0.71	40	85	95	62	56	99	-	-
Chang et al. (2005)										
NF Nanomax 50	396	1.76	12	88	89	-	20	97	0.60	1.2
RO Nanomax 95	396	1.76	96	98	99	-	98	99	1.11	3.8
Turner et al. (2002)										
NF 2540 ESNA	670	3.69	26	92	90	-	63	94	2.4	6.9
Riley (2005)										
NF E4-2200-DLX	804	4.57	24	89	78	-	6	91	1.8	4.3
Tarquin, et al. (Unpublished)										
NF	2015	10.3	33	65[2]	73	30	4	91	3.9	11.2
Ferjani, et al. (2004)										
NF PMHS	4100	12.1	84	95	98	100	87	98	14.7	24.0
Le Gouellec and Elimelech (2002)										
NF NF-90	17,740	22.6	94	98	98	-	91	99	86.5	48.6
NF NF-90	23,480	53.5	96	99	99	-	92	99	87.0	49.2

[1] The SAR value shown here is based on an assumed recovery rate of 80%

[2] This number is questionable and can be as high as 82% based on the concentrate analysis

The rejection rates for Na and Cl are highly variable, and at first glance, may appear to be solely dependant upon membrane types. However, the rejection of these elements is inter-related. Permeate water quality data (Table A-2 in the Attachments) show that the concentration of Na in the permeate is approximately equal to or slightly higher than that of Cl in chemical equivalent. This pattern is related to the fact that the rejection rate of SO_4 is nearly 100%, and that Na is more mobile than Ca or Mg through nanofiltration membranes. Putting it differently, Na ions are present in the permeate to achieve a charge balance with chloride ions or vice versa. An exception to this rule is reported by Riley (2005) where Na in the permeate was considerably higher than that of Cl. It is possible that the membrane used (E4-2200-DLX by Osmonics) has a low rejection rate for HCO_3. Otherwise, the data shown do not satisfy the charge balance.

The fact that Na ions permeate at a concentration comparable to that of Cl in chemical equivalence indicates that Na remains in the concentrate if SO_4 is the dominate ion, unless Ca and Mg concentrations exceed the SO_4 concentration. In the current study by Tarquin (Table A-2), sodium ions, but not Ca or Mg, are still the main cation in the concentrate. The feed water in this case is rich in Na and SO_4. The SAR of the concentrate was slightly higher than the SAR of feed water: 11.2 against 10.3. The increase in SAR is caused by the concentration effect,

meaning that the SAR, by definition, increases with increasing TDS, even though the ionic composition ratio remains the same, Eq. 17. In the estimate of SAR at 5 Mm^3/mo, the SAR of the concentrate is estimated at 10.6, which is still slightly higher than the SAR of feed water (Table 7). The SAR value which directly impacts the cation exchange reaction would be reduced by dilution, but will increase due to the increased formation of sulfate-divalent cation ion-pairs (e.g., Rao et al., 1968). The ion-pairs account for about 1/3 of the divalent cations in a solution dominated by SO_4 ions. In the example shown in Table A-2, the effective SAR from the preliminary tests increases from 11.2 to 15.8 in the concentrate. Dilution of the concentrate with the river water, as will be discussed later, lowers the SAR of the concentrate, but usually not below the SAR of the water used for blending. In any case, the SAR of the NF concentrate is not lower than that of the feed water (Table 6) except when chloride is the dominant anion, such as the case studied by Chang et al. (2005). However, if a NF membrane high in Cl rejection rate is used, such as the cases reported by Turner et al. (2002), Ferjani et al. (2004), as well as by Le Gouellec and Elimelech (2002), the SAR of the concentrates actually exceeds that of the feed water as the NF membrane functions in a manner similar to a RO membrane.

Table 7. Feed water quality at river flow rates of 5 and 10 Mm^3/mo, the assumed rejection rates, and the estimated quality of permeate and concentrates at the recovery rate of 80%.

	TDS	EC	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4	∑C	∑A
	me/L	dSm^{-1}	$(mmol/L)^{1/2}$	- - - - - - - - - - - - -			meq/L			- - - - - - - - - - - - -	
Feed Water (Dec-Feb)											
5 Mm^3/mo	50.1	2.5	7.7	16.3	6.4	2.6	5.6	8.4	10.8	25.3	24.8
7 Mm^3/mo	44.7	2.3	6.9	14.2	6.0	2.4	5.2	7.4	9.5	22.6	22.1
10 Mm^3/mo	39.8	2.0	6.2	12.3	5.5	2.2	4.8	6.5	8.3	20.0	19.8
Rejection rates assumed for nanofiltration (%)											
Case A[1] -	-	-	-	(49)	(90)	(90)	(98)	(0)	(98)	-	-
Case B[1] -	-	-	-	(34)	(70)	(70)	(30)	(5)	(90)	-	-
Ion Balance in Rejected Water Prior to the Concentration Process											
5 Mm^3/mo A	32.2	-	4.0	8.0	5.8	2.3	5.5	0.0	10.6	16.1	16.1
5 Mm^3/mo B	23.6	-	3.1	5.5	4.5	1.8	1.7	0.4	9.7	11.8	11.8
10 Mm^3/mo A	25.6	-	3.3	6.0	4.9	1.9	4.7	0.0	8.1	12.8	12.8
Ion Concentration in NF Permeate											
5 Mm^3/mo A	17.9	0.9	12.4	8.3	0.6	0.3	0.1	8.4	0.2	9.2	8.7
5 Mm^3/mo B	26.2	1.3	9.4	10.7	1.9	0.7	3.9	8.0	1.1	13.3	12.9
7 Mm^3/mo A	15.8	0.8	11.2	7.2	0.6	0.2	0.1	7.4	0.2	8.1	7.7
10 Mm^3/mo A	13.8	0.7	10.1	6.3	0.6	0.2	0.1	6.5	0.2	7.0	6.8
Ion concentration in concentrate at 80% recovery											
Nanofiltration											
5 Mm^3/mo A	178.7	9.0	10.6	48.2	29.4	12.0	27.6	8.4	53.1	89.6	89.1
7 Mm^3/mo A	160.3	8.1	9.6	42.0	27.6	11.0	25.6	7.4	46.7	80.6	79.7
10 Mm^3/mo A	143.2	7.2	8.6	36.4	25.6	10.2	23.6	6.5	40.9	72.2	71.0
RO Reject Concentration at 80% recovery											
5 Mm^3/mo	250.0	12.5	17.2	81.5	32.0	12.5	28.0	42.0	54.0	126.0	124.0
7 Mm^3/mo	223.5	11.3	15.5	71.0	30.0	12.0	26.0	37.0	47.5	113.0	110.5
10 Mm^3/mo	199.0	10.0	13.9	61.5	27.5	11.0	24.0	32.5	41.5	100.0	99.0

1Mm^3/mo=8.66 MGD

[1] - Case A: assumed to be an ideal case to minimize Na in the concentrate. Case B: the preliminary data from ongoing testing by Tarquin and his associate.

If the objective is to minimize Na concentrations in the concentrate, the types of membrane used by Riley (2005), and currently used by Tarquin (Unpublished) are preferred. We assumed rejection rates of 90% for Ca and Mg, 98% for SO_4 and HCO_3, and zero for Cl as a potential scenario for an ideal nanofiltration which meets the stated objective (Table 7). The rejection rate of 49% for Na ions was determined by the charge balance. Included in the analyses (marked as Case B) are the rounded rejection rates, computed from the preliminary data of Tarquin and his associates. The ion concentrations of the permeate and the concentrate from the NF process at these rejection rates computed by Eqs. 4 and 7, are given in Table 7. Note that the SAR of the NF concentrate is slightly lower than the case studied by Tarquin, mainly because the SAR of feed water is lower. Also included in the table is the concentrate concentration when all the ions were assumed to be rejected, a situation similar to reverse osmosis. The SAR of the concentrate from the NF process is significantly lower than that from the RO process, but still too high to be acceptable in clayey Entisols of the El Paso Valley, which occupy ¾ of the irrigated land (Miyamoto, 2000).

Salt Concentration after Blending

Feed Water Blending: The availability and quality of shallow well water found along the Rio Grande or returnflow drains are yet to be complied. For the sake of calculation, it was assumed that 2 Mm^3/mo (17.3 MGD or 24,940 gpm) of shallow ground water is available for pumping during winter months when the riverflow decreased to 5 Mm^3/mo. The concentrations of the well water which yields the same as those existing at a riverflow rate of 7 Mm^3/mo was then calculated by Eq. 18. If the salt concentration of the riverflow at 7 Mm^3/mo are to be maintained at the on–going level (mainly to avoid exceeding the TDS and Cl limits), the water to be used for blending must be comparatively low in TDS (1044 mg/L) as well as in Cl (173 mg/L) as shown under the heading of "Hypothetical Blending Water" in Table 8. These estimates apply to a situation where blending water is assumed to be added at a steady rate of 2 Mm^3/mo to the riverflow of 5 Mm^3/mo. If the blending water is added to riverflow greater than 5 Mm^3/mo, water of higher TDS and Cl can be used without significantly affecting these water quality parameters.

Permeate Blending: It is customary to expect that permeate has low enough salt concentrations to allow for blending prior to delivery. The permeate from the current pilot study noted as "Case B" yield a TDS of 867 mg L^{-1}, when riverflow of 5 Mm^3/mo is assumed to be treated (Table 8). When the concentration of the feed water was 2, 015 mg/L at riverflow rates less than 5 Mm^3/mo, the measured TDS of the permeate was 1,099 mg/L (Table A-2). During the period from October through November, the average salinity of the feed water is 1,851 mg L^{-1} at 5 Mm^3/mo (Table 5), thus the average TDS of the permeate is expected to be around 945 mg/L. At this range of TDS in the permeate, there is little room for blending with river water, as it raises TDS. The permeate from "Case A" scenario is lower than "Case B" in terms of TDS, but its quality could exceed the Cl limit of 300 mg/L, unless the flow reaches about 7 Mm^3/mo, which is close to the median flow during December through January. Another option would be to use a NF membrane with an elevated rejection of Cl.

Table 8. Estimates of water quality when the permeates are blended with the feed water.

		TDS	SAR	Na	Ca	Mg	Cl	SO_4
		mg/L	$(mmol/L)^{1/2}$	----------mg/L----------				
NF Permeate	Case[1] -							
5 Mm^3/mo	A	523	12.4	191	13	3	299	10
5 Mm^3/mo	B	867	9.4	246	38	8	284	53
7 Mm^3/mo	A	453	11.1	166	12	3	263	9
10 Mm^3/mo	A	404	10.1	145	11	3	232	8
Riverwater (Dec - Feb)								
5 Mm^3/mo		1699	7.6	375	129	32	299	520
7 Mm^3/mo		1512	6.9	327	120	29	263	456
10 Mm^3/mo		1350	6.2	283	111	27	232	399
Hypothetical Blending Water								
2 Mm^3/mo [2] -		1044	5.0	207	97	21	173	296
Blended Water (NF Permeate with Riverwater), Blend Ratio 0.25[3] -								
5 Mm^3/mo		758	10.4	228	36	9	299	112
7 Mm^3/mo		665	10.3	198	34	8	263	98
10 Mm^3/mo		593	9.3	173	31	8	232	86
Blended Water (RO Permeate with Riverwater), Blend Ratio 1.0 (4/4, 8/8 MGD)								
5 Mm^3/mo		849	5.4	188	65	16	150	260
10 Mm^3/mo		675	4.4	142	56	14	116	200

[1] - Two cases of rejection rates given in Table 7.

[2] - The estimated compaction of blend water when 2 Mm^3/mo to make the river water at 7 Mm^3/mo without changing the composition.

[3] - Blending ratio of 0.25 includes 4 MGD of the permeate blend with 1 MGD of the filtered river water.

The chemical composition of blends when the permeate from "Case A" is mixed with river water at a blending ratio of 0.25 (Q_B/Q_P of Eq. 12) is shown in Table 8. (River water is assumed to be treated for removal of other contaminants prior to blending). According to this estimate, TDS will be around 758 mg/L, but Cl concentrations can exceed its limit. The SAR of the NF permeate and its blend with river water remains above 10 until the riverflow increases to 10 Mm^3/mo (Table 8). If a RO system is used, the permeate can be blended with river water at a blending ratio of 1:1 without exceeding the TDS limit. We assumed that the permeate from a RO system has zero salinity for simplicity. Under the RO option, the concentration of Cl remains well below the regulatory limit. As noted in the footnote of Table 8, the permeate from the NF process produces a total of 5 MGD deliverable product water which includes 1 MGD of blending water. In the case of RO systems, the same quantity of product water can be obtained with a membrane process capacity of 2.5 MGD in terms of permeate flow or 3 MGD of diversion and filtration at an assumed 80% recovery.

A rigid estimate of blending ratios, using Eq. 13A, which are permissible under the target water quality goal, is shown in Table 9. For TDS, a target salinity of 800mg/L was used, instead of the regulatory limit of 1000 mg/L, as the existing delivery salinity is low, 625 mg/L. According to this estimate, the upper limit of the blending ratios (R_B) range from 0.31 to 0.72, depending on the flow which controls salinity of the river water. If the permeate from the RO process is assumed to contain no salt for simplicity, the permissible level of blending is higher, ranging from 0.89 to 1.45, depending on the flow rate. If an alternative source of water is available, which has lower salinity than river water, the permissible level of blending would

increase. The permissible blending ratio for SO_4 is higher than that for TDS, thus can be ignored in this case. There is little difference in R_B for SO_4 between the NF and the RO processes, because both processes have a high rejection rate for SO_4. The permissible R_B for Cl was not calculated, because its concentration in the blending water (river water) is lower or approximately the same as the target concentration.

Table 9. Permissible blending ratios, the quantity of permeate required to meet the desired TDS and SO_4 limits, and the estimated salt load in the discharge.

Riverflow (Mm3/mo)	5	7	10
Projected River Water quality			
TDS (mg/L)	1699	1512	1350
SO_4 (mg/L)	520	456	399
Cl (mg/L)	299	263	232
SAR	12.4	11.1	10.1
Target Water Quality (Examples)			
TDS (mg/L)	800	800	800
SO_4 (mg/L)	250	225	200
Cl (mg/L)	275	275	275
Existing Delivery Quality (EPWU)			
TDS (mg/L)	625	625	625
SO_4 (mg/L)	217	217	217
Cl (mg/L)	106	106	106
SAR	4.4	4.4	4.4
Permeate Quality (Nanofiltration)			
TDS (mg/L)	523	453	404
SO_4 (mg/L)	10	9	8
Cl (mg/L)	299	263	232
Blending Ratio R_B by Eq. (13A)			
NF Process			
TDS	0.31	0.49	0.72
SO_4	0.89	0.94	0.96
Cl	-	-	-
RO Process [1]			
TDS	0.89	1.12	1.45
SO_4	0.93	0.97	1.0
Cl	11.5	-	-
Permeate required for 10 MGD of potable water production			
NF Process (MGD)	7.64	6.72	5.81
RO Process (MGD)[1]	5.29	4.71	4.07
Estimated salt load of the concentrate (tons/day)			
NF Process (MGD)	46.2	36.2	28.1
RO Process (MGD)	42.3	33.7	25.7

[1] - The salt concentration of the permeate from a RO process is assumed to be zero for simplicity.

The quantity of permeate required to produce a 10 MGD of the deliverable potable water, computed by Eq. 13B, is shown in Table 9. The permeate quantity required for a NF process is higher than that for a RO process. This leads to a proportionally greater volume of the concentrate at a fixed rate of recovery (80%). The salt load of the discharge was estimated by

multiplying the salt concentration shown in Table 9 to the concentrate volume at a recovery rate of 80%. Results indicate that the salt discharge from the RO process is slightly lower than that of NF. However, the Na concentration in the concentrate from RO would be greater by a factor of 2, as compared to the concentrate from the NF process.

Dilution of Concentrate: The most convenient way to dilute the concentrate would be to blend with river water. Examples of water quality changes caused by dilution at an assumed riverflow rate of 5 Mm^3/mo are shown in Table 10. The estimate for 7 and 10 Mm^3/mo is shown in Table A-3 of the Attachments. The dilution considered consisted of three levels; 4.5, 15.5, and 37.0, and coincides with membrane process capacities of 5, 10, and 20 MGD, and concentrate volumes of 1, 2 and 4 MGD at 80% recovery. The actual diversion must include 1, 2.5, and 5 MGD for plant capacities of 5, 10, and 20 MGD for permeate blending.

Table 10. Estimates of water quality when the concentrates from membrane process capacities of 5, 10, and 20 MGD are blended with river water (5 Mm^3/mo), then the munipal effluent.

		TDS	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4
		mg/L	$(mmol/L)^{1/2}$	------mg/L----------					
Concentrate from NF processes at 80% recovery									
5 Mm^3/mo		6391	10.6	1110	594	147	1683	299	2558
7 Mm^3/mo		5700	9.5	966	552	134	1543	263	2242
10 Mm^3/mo		5108	8.6	837	512	124	1440	232	1963
Concentrate from RO processes at 80% recovery									
5 Mm^3/mo		8458	17.2	1875	640	152	1708	1491	2592
7 Mm^3/mo		7559	15.4	1633	600	146	1586	1314	2280
10 Mm^3/mo		6709	13.9	1415	550	134	1464	1154	1992
Diluted water (NF concentrate with riverwater at riverflow of 5 Mm^3/mo)[2J]									
Capacity (MGD)	Q/Qc								
20	4.5[1]	2552	8.1	509	214	53	586	299	891
10	15.5	1982	7.8	420	157	39	423	299	644
5	37.0	1820	7.7	394	141	35	377	299	574
	∞	1699	7.4	375	129	32	342	299	520
Diluted Water (RO concentrate with riverwater at riverflow of 5 Mm^3/mo)[2J]									
20	4.5	2927	10.1	648	222	54	590	516	897
10	15.5	2107	8.6	466	160	39	425	371	646
5	37.0	1874	8.1	414	142	35	378	330	575
Blended Water (NF concentrate diluted with riverwater and Haskell return)[3] -									
20	22:15	1843	7.4	387	146	36	406	272	587
10	33:15	1614	7.4	354	123	30	336	278	487
5	38:15	1532	7.4	342	114	28	311	280	451
Blended Water (NF concentrate with riverwater and blended with Haskell, Bustamante return)[2] -									
20	22:42	1519	7.6	341	108	27	298	309	411
10	33:42	1420	7.6	326	99	25	268	307	373
5	38:42	1378	7.6	320	95	24	256	307	357

[1] - (Q/Qc);The dilution ratios of 4.5, 15.5 and 37.0 coincide with the concentrate mixing with the riverwater at the membrane process rates of 20, 10 and 5 MGD at the riverflow of 5 Mm^3/mo (43 MGD).

[2J] The estimate at the river flow rates of 7 and 10 Mm^3/mo is shown in Attachment A-3.

[3] - Salinity of Haskell return during Dec-Feb averages 800mg/L, and that of the Haskell and Bustamante discharges combined 978 mg/L.

According to the estimate shown in Table 10, TDS decreases from 6,390 to 2,550 mg/L after the concentrate (4 MGD) is diluted with 18 MGD of the remaining riverflow at a membrane process capacity of 20 MGD. The riverflow prior to diversion was assumed to be 5 Mm^3/mo or 43 MGD. When the membrane process capacity is assumed to be 10 and 5 MGD, the dilution ratio increases to 15.5 and 37, respectively. At 5 MGD process capacity, the TDS of the blend is higher than the salinity of river water at 5 Mm^3/mo by 120 mg/L or by 7%. The SAR of the concentrate decreases from 10.6 to 7.7 at a dilution ratio of 37. The changes in water quality at

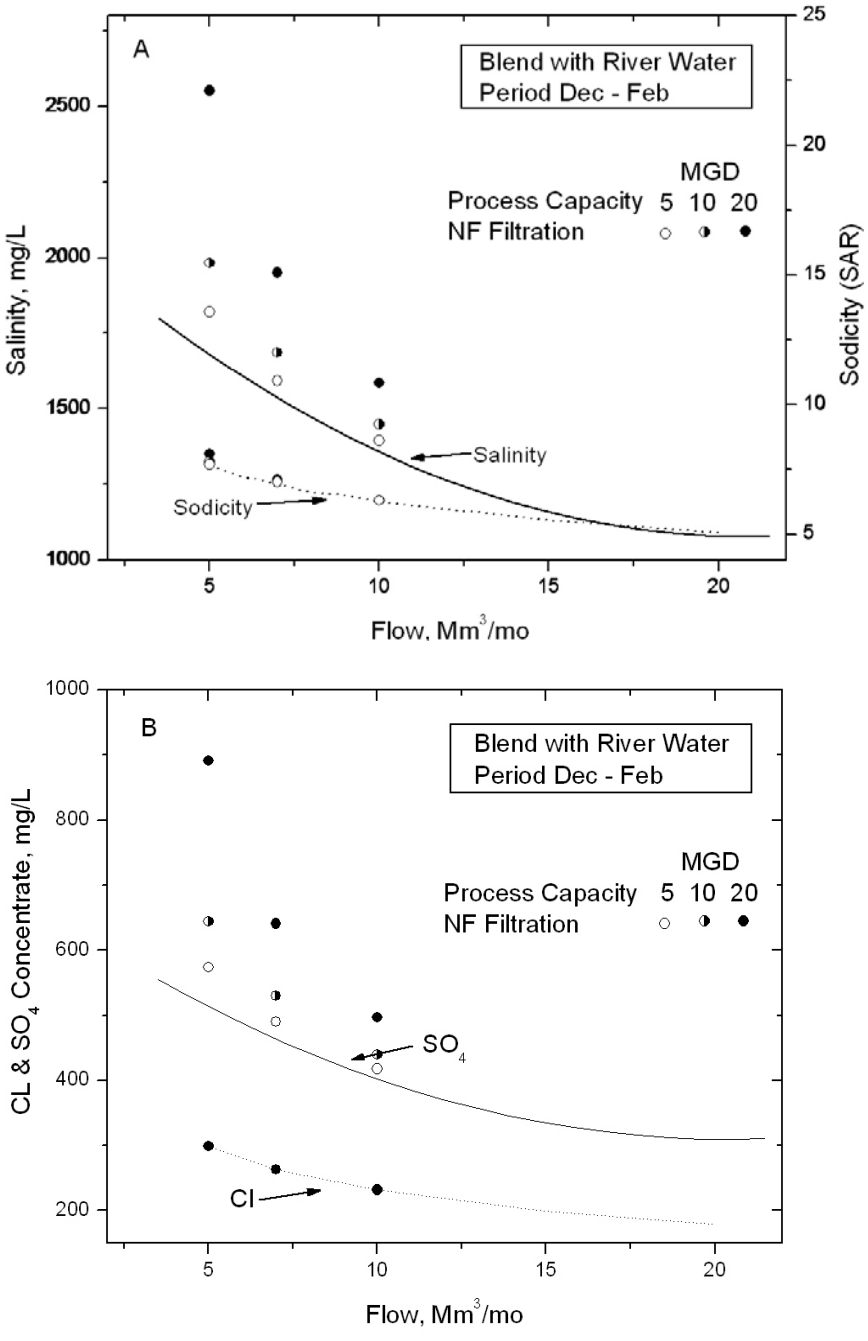

Fig. 7. Salinity, sodicity, and ion concentrations of blends when the NF concentrate is to be discharged into the river water.

the riverflow rates of 7 and 10 Mm^3/mo are also given in Fig. 7. The solid lines in Fig. 7 represent salinity, sodicity, and the concentrations of Cl and SO_4 when NF concentrate is assumed to be discharged into the river water flowing at 5, 7, and 10 Mm^3/mo. Note that salinity as well as the SO_4 concentration of the blend increase with increasing the process capacity and decreases significantly with increasing the flow of the river. This is a sharp contrast to the SAR and the concentration of Cl ions, both of which changes little with increasing the process capacity. The small changes in Cl concentration are related to the low rejection rate of this ion.

Table 11 shows the effect of concentrate disposal to the riverflow on water quality when NF and RO processes are assumed to be used. The process capacity was assumed to be 5, 10 and 20 MGD. Since the permeate is assumed to be blend with the river water, the diversion is set at 6, 12.5, and 25 MGD for the membrane process capacity of 5.10 and 20 MGD. At low dilution rates, e.g., the concentrate discharge of 4 MGD to the low riverflow of 5 Mm^3/mo, salinity of the blend from the RO process is significantly higher than that from the NF process. However, when the dilution rate reached 15.5, the difference in salinity between the NF concentrate and the RO concentrate became less than 3% (Table 11). The main difference between the concentrates from NF and RO is the impact on sodicity. In the case considered (5 Mm^3/mo flow), the SAR of the concentrate from RO begins at 17.2, which is considerably higher than that of the NF process of 10.6 (Table 11). Nonetheless, dilution reduces the difference, e.g., less than 10% at a dilution factor of 37. Blending the diluted water with municipal effluent further reduces salinity, but the impact of concentrate discharge remains significant (Table 11).

Table 11. Estimate of the water balance, and projected changes in water quality for assumed desalting at 5, 10 and 20 MGD capacitites.

Riverflow		5 Mm^3/mo				7 Mm^3/mo			
(MGD)			(43)				(60)		
Capacity (MGD)		-	5	10	20	-	5	10	20
Diversion (MGD)		0	6	12.5	25	0	6	12.5	25
Riverflow after diversion (MGD)		43	37	31	18	86	54	47.5	35
Concentrate (MGD)		0	1	2	4	0	1	2	4
Dilution Ratio (riverflow/concentrate flow)		∞	37	15.5	4.5	∞	54	23.7	8.75
Water quality after dilution of NF concentrate									
TDS	(mg/L)	1699	1820	1982	2552	1517	1593	1687	1949
SAR	$(mmol/L)^{1/2}$	7.4	7.7	7.8	8.1	6.9	7.0	7.0	7.1
SO_4	(mg/L)	520	574	644	891	457	490	530	641
Cl	(mg/L)	299	299	299	299	268	268	268	268
Water quality after dilution of RO concentrate (all in mg/L)[1] -									
TDS	(mg/L)	1699	1843	2035	2710	1517	1627	1763	2139
SAR	$(mmol/L)^{1/2}$	7.4	8.1	8.6	10.1	6.9	7.2	7.2	7.2
SO_4	(mg/L)	520	575	646	897	457	490	531	644
Cl	(mg/L)	299	330	371	516	268	284	304	357

[1] - The numbers shown are based on the assumption of equal permeate flow between NF and RO processes. In reality, the permeate from RO processes can generate a greater quanity of blend water for delivery.

The quality of the blend shown in Tables 10 and 11 was estimated with a permeate production rate of 4 MGD. As noted in Table 9, the quantity of feed water which must be treated is lower for RO than for NF process, because the permeate from the RO process can be blended at a higher blending ratio. If this reduction in the processing is incorporated, the concentrate production from RO and its impact on salinity of the blend are reduced significantly.

Discussion

Availability of Source Water

According to the analysis of riverflow by Riley (2005), a monthly flow of 4.6 Mm^3/mo (40 MGD) has occurred 80% of the time for the past 68 years. The median flow during winter months (December through February) was computed to be 8.6 Mm^3/mo (75 MGD), which is 5 to 7 times the irrigation demand for the current winter crop production. In other words, there would be an adequate amount of water to support a desalting plant, as long as the river flows at or near the median flow. When the flow decreases below 5 Mm^3/mo (43 MGD), however, there may be competing demand for irrigation. If the concentrate is to be discharged into the irrigation system, ample flow, perhaps no less than 5 Mm^3/mo appears to be needed for adequate dilution of the concentrate, even with a relatively small plant size of 5 to 10 MGD.

The need for a diversion increases with the size of the plant; 6, 12 and 25 MGD for diversion for the processing capacities of 5, 10, and 20 MGD, including 25% of permeate blending (Table 11). If the riverflow is 5 Mm^3/mo (43 MGD), the flow balance would be 37, 31 and 18 MGD, which would yield the dilution ratios of 37, 15.5, and 4.5, respectively. There are significant differences in TDS between river water and the blend of river water and the concentrate at low dilution ratios (Table 11 and Fig. 7). A riverflow at 5 Mm^3/mo may not be sufficient to adequately support a processing capacity of 20 MGD, but perhaps can support a lower capacity range of 5 to 10 MGD.

One way to cope with the riverflow shortage would be to pump shallow ground water into the river or into a feeder when riverflow decreases to an order of 5 Mm^3/mo. In order to bring the flow to 7 Mm^3/mo, 15 wells of 800 gpm would be required. Selection of appropriate wells is a separate task, and can be an involved task, as the area above the geological bottle-neck currently provides both fresh and saline ground water. If saline ground water is to be utilized, the project scope changes from returnflow utilization to a conjunctive use scenario. Salinity of well water for blending cannot be any higher than that of the riverflow, preferably as low as 1040 mg/L, if the existing flow and salinity relationship in the river are to be maintained for a ease of plant design.

Membrane Process Selection

To minimize the salt load of the concentrate, especially that of monovalent ions, nanofiltration with a low Na and Cl rejection rate is preferred. However, when salinity of feed water is high, quality of permeate may not meet the water quality targets or limits. According to preliminary test results given in Table A-2, permeate quality did not meet the TDS limit of 1000 ppm or the Cl limit of 300 mg/L when TDS of feed water was 2015 mg/L (which occurs at a

flow rate of less than 5 Mm^3/mo). At a riverflow rate of 5 Mm^3/mo, the estimated salinity of the permeate is below 1,000, but the Cl concentration may not meet the required limit (Table 8), unless a membrane with higher Cl rejection is used.

These results raise a question on appropriate membrane selection. Nanofiltration offers a potential advantage of limiting Na retention in the concentrate. In the present case, nanofiltration seems to provide a Na rejection rate of around 49%. The amount of Na retained in the concentrate is about half of that in the brine reject from a RO process. However, this advantage does not reflect upon the SAR of the concentrate, because the concentration factor increases the SAR. When diluted with river water, the difference in SAR between NF and RO becomes less obvious, as the SAR of the river water masks the difference. In addition, the actual salt load of the concentrate is likely to be lower from the RO process than the NF process (Table 9). In spite of this limited impact on SAR (which is a measure used mainly to gauge water quality impacts on soil structure and permeability), it should be noted that nanofiltration reduces Na to Ca ratios, as well as Cl to SO_4 rations (Fig. 7). This can impact plant growth more so than soil structure.

One additional disadvantage of NF is that the SAR as well as the concentrations of Na and Cl of the permeate can be too high for landscape irrigation uses. At low salinity (TDS < 1000 mg/L), the SAR of around 6 can cause significant water infiltration problems in Entisols (Miyamoto, 2006). More importantly, both Na and Cl concentrations in excess of 150 mg/L, increase foliar salt damage on broadleaf tress, shrubs, and some flowers when foliage is wet by sprinklers (Miyamoto and White, 2002; Miyamoto et al., 2004a and b). The Na ions, which did not remain in the concentrate, must appear in the permeate. In the case of sodic feed water, it can generate unfavorable product water for urban irrigation uses, unless water of low Na and Cl concentrations is available for blending.

Some constraints associated with a NF process can be eliminated by using a two-stage process involving NF, followed by a RO process. The brine reject from a RO process containing mostly NaCl should be isolated from irrigation systems. However, the disposal of brine reject is not an easy task and can add significantly to the cost of water production. A NF membrane with moderate Na and Cl rejection or a RO process may be an alternative.

Water Management Practices

Water delivery practices, especially routing of the concentrate, are likely to affect dilution, thus salinity of the blend. If the concentrate is to be discharged to the American Canal, it would eventually be diluted by river water and reclaimed water (which has lower salinity than the river water). However, there are diversions for irrigation, prior to reaching the Bustamante Plant. If the concentrate is discharged to the Franklin Canal, no blending with municipal return may occur. In these cases, the water available for dilution of the concentrate is practically limited to the river water. Discharge of NF concentrate from 5 and 10 MGD process plant can potentially increase salinity of the blend by 7 and 16% respectively at a riverflow rate of 5 Mm^3/mo (Table 10 and Fig. 7). If a NF membrane with a higher rejection rate for Na and Cl is used, the TDS of the blend will increase.

Alternatively, the concentrate could be discharged into a collection system for Haskell WWTP, instead of the canal systems, provided that the collection system can accommodate an additional flow of 1 MGD. Quality degradation of the municipal return would be minimal, and should not affect reuse activities, which take place mostly during spring to summer months for landscape irrigation. The impact of concentrate disposal should not be greatly different between the NF and the RO system, as the municipal return will bring Na and Cl ions (which were previously passed) back into the system. Disposal of the concentrate into agricultural drains or other saline water stream may be another option if can be agreed upon with applicable entities.

Research Needs

The primary objective of Task III of this cooperative agreement is to evaluate the impact of concentrate disposal into river water on quality of irrigation water. The initial assessment was that NF concentrate discharge into the river water will not increase SAR. In fact, some thought that SAR should decrease because the concentrate from NF processes would be enriched with Ca and Mg. Preliminary data from the ongoing testing of NF processes, as well as a review of other experiences, indicate that feed water quality at this site is such that the SAR of the concentrate is likely to stay at the same level as feed water (or higher if RO processes or a NF membrane with a higher Cl rejection rate is used). In addition, concentrate discharge into irrigation systems will inevitably increase the total dissolved salt content of the irrigation water supply.

A modest increase in Ca and Mg concentrations is not enough to cause a reduction in SAR due to the concentration effect. However, the increase in Ca, Mg and SO_4 proportion over Na or Cl will lower ion activities. Salt hazard to plant growth is usually caused by excessive ion activities, but not necessarily by the total dissolved salt concentration. In addition, some crops are known to be susceptible to Cl toxicity. In such cases, an increase in SO_4 concentration could be less harmful. Research is needed to demonstrate that a modest increase in divalent ions may or may not reduce crop establishment and growth of salt or Cl sensitive winter crops, such as onions. This topic is scheduled to be addressed in the follow-up phase of this project.

The use of NF may not necessarily free us from the task of concentrate handling. At this test site in El Paso, it appears that the two-stage treatment (NF first, followed by an RO process) may be an option. This will make it necessary to handle the brine reject consisting of mostly NaCl. If a straight RO process or NF with high Na and Cl rejection rates, instead of the two-stage process is to be used, concentrate disposal, besides discharge into irrigation systems, may have to be considered.

There is a need to prepare some type of guidelines for assessing concentrate suitability for irrigation. Without, the design of membrane processes can become not compatible with irrigation water quality guidelines. Most of the NF process, for example, is ideal for reducing hardness of gypsic water for urban water supply, while providing the concentrate potentially valuable for irrigation. When combined with a RO process, it also helps isolate NaCl salts from moderately saline water affected by dissolution of halite or contaminated with seawater. When feed water is rich in Na and SO_4 ions, however, the concentrate composition would be similar to that of the feed water. The effect of these changes in water composition on quality of irrigation water must be articulated.

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Attachments

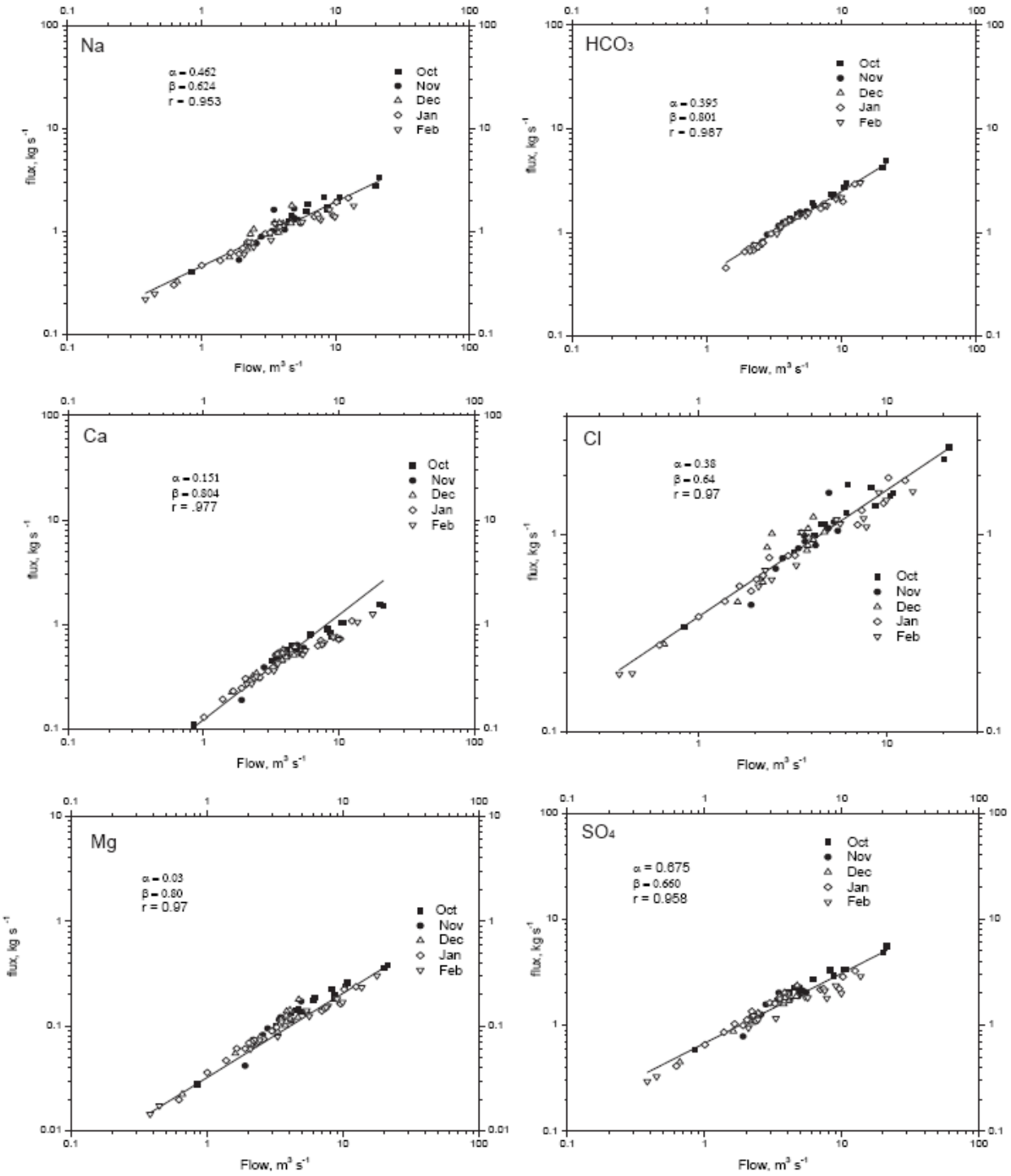

Fig. A-1. The relationship between salt flux and momentary flow rates (1970-2000).

Table A-1. The quality of water available for irrigation during off seasons

	Oct	Nov	Dec	Jan	Feb	Average
	----------mg/L----------					
Discharge						
River water (1936 - 2004, USGS)						
median Mm^3/mo	21.3	11.1	8.8	7.4	9.7	11.7
MGD	183	96	76	64	84	101
Haskell WTP (2001 - 2005, EPWU)						
mean Mm^3/mo	1.88	1.61	1.55	1.48	1.78	1.66
MGD	16	16	16	13	16	15.4
Bustamante WTP (2001 - 2005, EPWU)						
mean Mm3/mo	3.17	3.09	3.14	3.06	3.11	3.114
MGD	27	27	27	26	27	26.8
Salinity						
River water (1970 - 2002, excluding 1985, IBWC)						
mean	1226	1400	1459	1411	1263	1352
SD	237	242	203	323	392	279
Haskell WTP (2001 - 2005, EPWU)						
mean	886	829	804	773	836	826
SD	59	38	78	107	87	74
Bustamante WTP (2001 - 2005, EPWU)						
mean	1160	1085	1102	1086	1036	1094
SD	52	25	98	74	68	63
Sodium Concentration, means						
River water	276	323	350	327	311	317
Haskell WTP	225	217	210	204	212	214
Bustamante WTP	273	279	287	278	269	277
Calcium Concentration, means						
River water	118	128	131	118	108	121
Haskell WTP	59	49	47	45	48	50
Bustamante WTP	71	59	62	55	55	60
Magnesium Concentration, means						
River water	27	31	32	29	27	29
Haskell WTP	14	12	11	11	11	12
Bustamante WTP	18	15	16	14	14	15
Bicarbonate Concentration, means						
River water	277	322	319	287	269	295
Haskell WTP	164	139	140	145	144	146
Bustamante WTP	141	151	142	155	150	148
Chloride Concentration, means						
River water	227	274	293	276	262	266
Haskell WTP	236	241	230	228	237	234
Bustamante WTP	303	352	377	349	351	346
Sulfate Concentration, means						
River water	448	504	522	499	440	483
Haskell WTP	179	139	139	136	148	148
Bustamante WTP	229	169	181	172	160	182

Mm^3/mo = 264 Mgals/mo ≈ 8.66 MGD

1 MGD = 1.55 cfs = 3785 M^3/day

Table A-2. Reported salt balance in nanofiltration and reverse osmosis process.

	TDS	SAR	Na	Ca	Mg	Σ Cat	HCO_3	Cl	SO_4	Σ An
	mg/L	- - - - - - - - - - - - - - - - - - - -				me/L	- - - - - - - - - - - - - - - - - - - -			
Lee, et al. (2003): Saline solutions, RO and NF membranes										
Feed NaCl (.1N solution)			100	0	0	100	0	100	0	100
$CaCl_2$ (.1N solution)			0	100	0	100	0	100	0	100
Rejection ratio (%)										
LFC			(96)	(99)	-	-	-	96	-99	
ESPA			(93)	(97)	-	-	-	93	-97	
ULP			(87)	(87)	-	-	-	87	-87	
HR			(96)	(98)	-	-	-	96	-98	
NF90			(77)	(77)	-	-	-	77	-77	
Mulford, et al. (1999): groundwater, nanofilter, NF 70										
Feed	483	0.71	1.24	5.40	0.63	7.27	1.62	1.52	3.87	7.01
Permeate										
Full scale (80-40)	86.5	0.96	0.48	0.80	0.06	1.34	0.52	0.68	0.06	1.26
Pilot (25-40)	96.9	1.15	0.74	0.80	0.03	1.57	0.62	0.67	0.04	1.33
Rejection Ratio (%)										
Full scale (80-40)	-	-	(61)	(85)	(90)	-	(68)	(55)	(98)	-
Pilot (25-40)	-	-	(40)	(85)	(95)	-	(62)	(56)	(99)	-
Chang, et al. (2005): Municipal effluent, Nonofiltration and Reverse Osmosis										
Feed	416	1.76	2.40	1.08	2.64	6.12	(3.06)	2.14	0.92	(6.12)
Permeate										
NF (Nanomax 50)	166	4.62	2.12	0.13	0.29	2.54	(0.79)	1.72	0.03	(2.54)
RO (Nanomax 95)	9	0.63	0.09	0.02	0.02	0.13	(0.07)	0.05	0.01	(0.13)
Rejection Ratio (%)										
NF	-	-	(12)	(88)	(89)	-	(74)	(20)	(97)	-
RO	-	-	(96)	(98)	(99)	-	(98)	(98)	(99)	-
Turner, et al. (2002): Riverwater, Nanofiltration 2540 ESNA Hydranautics										
Feed	710	3.69	5.70	3.60	1.16	10.5	(2.57)	3.00	4.79	(10.5)
Permeate	109	2.91	1.30	0.30	0.10	1.70	(0.33)	1.10	0.27	(1.7)
Rejection Ratio (%)	-	-	(76)	(92)	(90)	-	(87)	(63)	(94)	-
Riley (2005): Riverwater, Nanofilter, E4-2200-DLX by Osmonics										
Feed	815	4.57	7.10	3.18	1.64	11.9	(3.62)	4.10	4.20	(11.9)
Permeate	449	8.98	5.40	0.95	0.30	6.60	(2.42)	3.85	0.38	(6.6)
Rejection Ratio (%)	-	-	(24)	(89)	(78)	-	(33)	(6)	(91)	-
Tarquin, et al. (Unpublished Preliminary data): Irrigation Returnflow, Nanofilter by Osmonics										
Feed	2016	10.3	22.1	6.35	2.79	31.2	5.30	12.7	12.0	29.9
Permeate at recovery rates of										
68%	1100	12.0	14.7	2.25	0.74	17.68	3.7	12.17	1.04	16.91
Rejection Ratio (%)										
68%	-	-	(33)	(65)	(73)	-	(30)	(4)	(91)	-
Concentrate at recovery rates of										
68% Computed	3945.5	11.2	37.3	15.1	7.1	59.5	8.6	13.8	35.1	57.5
68% Measured	3885.5	11.1	39.2	17.4	7.3	63.9	7.0	12.4	35.0	54.4

Table A-2. Continued

	TDS	SAR	Na	Ca	Mg	Σ Cat	HCO_3	Cl	SO_4	Σ An
	mg/L	- - - - - - - - - - - - - - - - - - -				me/L	- - - - - - - - - - - - - - - - - - -			
Ferjani, et al. (2004): Saline water, Nanofilter, PMHS										
Feed	3367	12.1	36.6	10.4	7.85	55.0	2.80	32.9	18.4	(55.0)
Permeate	300	13.8	5.60	0.25	0.08	5.90	0	4.30	0.26	(5.9)
Rejection Ratio (%)	-	-	(84)	(95)	(98)	(89)	(100)	(87)	(98)	-
Le Gouellec and Elimelech (2002), Saline Agricultural Drainage Water, NF-90										-
Feed	18232	22.6	169	61.5	50.0	280	(7)	83.4	190	(280)
Permeate	673	10.2	9.13	0.85	0.74	10.7	(1.5)	7.7	1.5	(10.7)
Rejection Ratio (%)	-	-	(94)	(98)	(98)	-	(79)	(91)	(99)	-
Feed	27445	53.5	333	34.5	43.0	410	(65)	156	189	(410)
Permeate	879	29.7	14.1	0.2	0.25	14.6	(0.7)	12.9	0.98	(14.6)
Rejection Ratio (%)	-	-	(96)	(99)	(99)	-	(99)	(92)	(99)	-

Table A-3. Estimates of water quality after the concentrates are diluted with river water and blended with the treated municipal effluent.

		TDS	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4
		---mg/L---							
Feed water concentration (mg/L) at the river flow rates of									
5 Mm^3/mo		1699	7.7	375	129	32	342	299	520
7 Mm^3/mo		1517	6.9	327	120	29	316	263	457
10 Mm^3/mo		1350	6.2	283	111	27	292	232	399
15 Mm^3/mo		1180	5.5	240	102	24	266	199	342
Concentrate from NF processes at 80% recovery									
5 Mm^3/mo		6391	10.6	1110	594	147	1683	299	2558
7 Mm^3/mo		5719	9.6	968	552	133	1555	263	2248
10 Mm^3/mo		5108	8.6	837	512	124	1440	232	1963
Concentrate from RO processes at 80% recovery									
5 Mm^3/mo		8485	17.1	1875	645	160	1710	1495	2600
7 Mm^3/mo		7585	15.5	1635	600	145	1580	1315	2285
10 Mm^3/mo		6720	14.0	1415	555	135	1460	1160	1995
15 Mm^3/mo		5900	12.4	1200	510	120	1330	995	1710
		--- 5 Mm^3/mo ---							
Diluted water (NF concentrate with riverflow, 5Mm^3/mo)									
	Dilution Ratios								
20	4.5[1]	2552	8.1	509	214	53	586	299	891
10	15.5	1982	7.8	420	157	39	423	299	644
5	37.0	1820	7.7	394	141	35	377	299	574
Diluted Water (RO concentrate with riverwater)									
	Dilution Ratios								
20	4.5	2933	10.1	648	223	55	591	516	898
10	15.5	2110	8.6	466	160	40	425	371	646
5	37.0	1878	8.1	414	143	35	378	330	575
Blended Water (NF concentrate with riverwater and municipal return)									
	Dilution Ratios								
20	22:42	1519	7.6	341	108	27	298	309	411
10	33:42	1420	7.6	326	99	25	268	307	373
5	38:42	1378	7.6	320	95	24	256	307	357
		--- 7 Mm^3/mo ---							
Diluted water (NF concentrate with riverflow, 7Mm^3/mo)									
	Dilution Ratios								
20	8.75	1949	7.1	393	164	40	443	263	641
10	23.7	1687	7.0	353	137	33	366	263	530
5	54.0	1593	7.0	339	128	31	339	263	490
Diluted Water (RO concentrate with riverwater)									
	Dilution Ratios								
20	8.75	2139	8.2	461	169	41	446	371	644
10	23.7	1763	7.5	380	139	34	367	306	531
5	54.0	1627	7.2	351	129	31	339	282	490
Blended Water (NF concentrate with riverwater and municipal return)									
	Dilution Ratios								
20	40:42	1449	7.2	321	107	26	291	289	393
10	49:42	1360	7.2	307	99	24	265	286	359
5	56:42	1329	7.2	302	96	23	256	285	348

Table A-3. Continued

		TDS	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4
		----------mg/L----------							
		----------10 Mm^3/mo----------							
Diluted water (NF concentrate with riverflow, 10Mm^3/mo)									
MGD	Dilution Ratios								
20	15.0	1585	6.3	318	136	33	364	232	497
10	37.0	1449	6.3	298	122	30	322	232	440
5	80.0	1396	6.3	290	116	28	306	232	418
Diluted Water (RO concentrate with riverwater)									
	Dilution Ratios								
20	15.0	1686	7.0	354	139	34	365	290	499
10	37.0	1491	6.6	313	123	30	323	256	441
5	80.0	1416	6.4	297	116	28	306	243	419
Blended Water (NF concentrate with riverwater and municipal return)									
	Dilution Ratios								
20	65:42	1347	6.7	292	104	25	279	264	365
10	76:42	1281	6.6	282	97	24	260	261	340
5	81:42	1254	6.6	277	95	23	252	260	330

[1] - The dilution ratios (Q/Q_c) of 4.5, 15.5 and 37.0 coincide with the concentrate mixing with the riverwater at a plant capacity of 20, 10 and 5 MGD at the riverflow of 5 Mm^3/mo (43 MGD).